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(12) **United States Patent**
Azuma

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(45) **Date of Patent: Aug. 18, 2015**

(54) **SINGLE SENSOR TWO-SIDED CAMERA**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) Filed: **Jun. 30, 2014**

(51) **Int. Cl.**
H04N 5/335 (2011.01)
H01L 21/70 (2006.01)

(52) **U.S. Cl.**
CPC ***H04N 5/335*** (2013.01)

(58) **Field of Classification Search**
CPC H01L 27/0694
USPC 348/294, 308; 257/618
See application file for complete search history.

(56) **References Cited**

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2013/0063641 A1 * 3/2013 Venezia et al. 348/308

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Primary Examiner — Joel Fosselman
(74) *Attorney, Agent, or Firm* — Seyfarth Shaw LLP

(57) **ABSTRACT**

A single dual-sided image sensor simultaneously captures discrete images from two different perspectives using both a front-side and a back-side of the image sensor. The two different perspectives are extracted from a composite image for processing. The two cameras, as configured in a device, face in a same direction and are spatially offset.

21 Claims, 10 Drawing Sheets

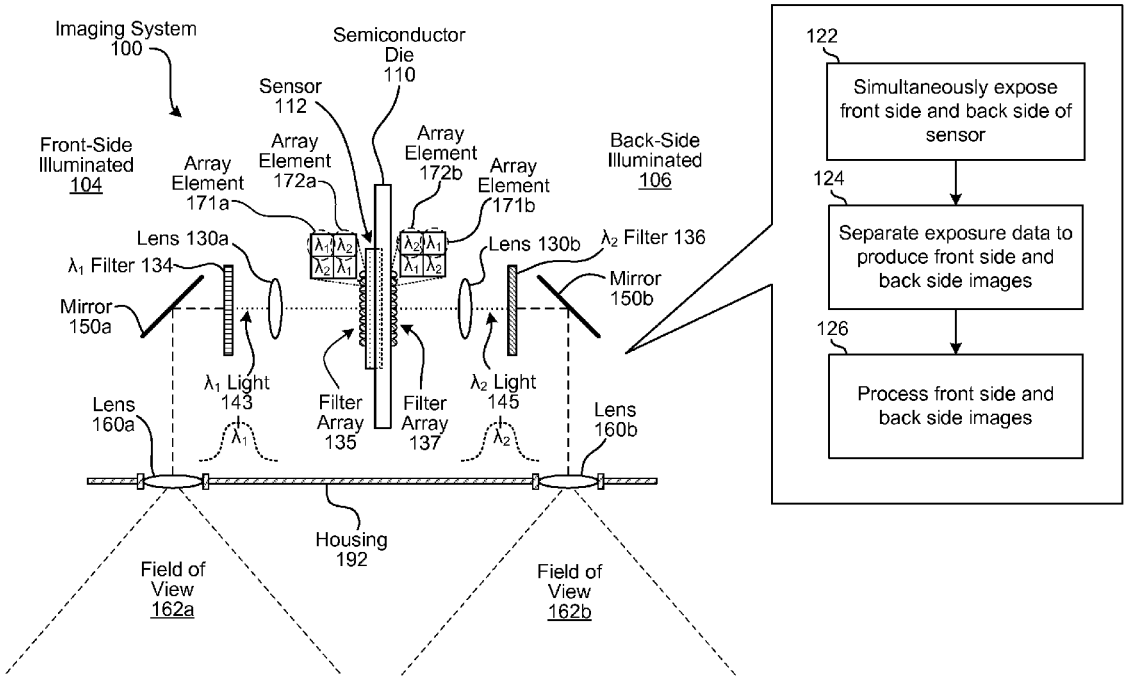


FIG. 1

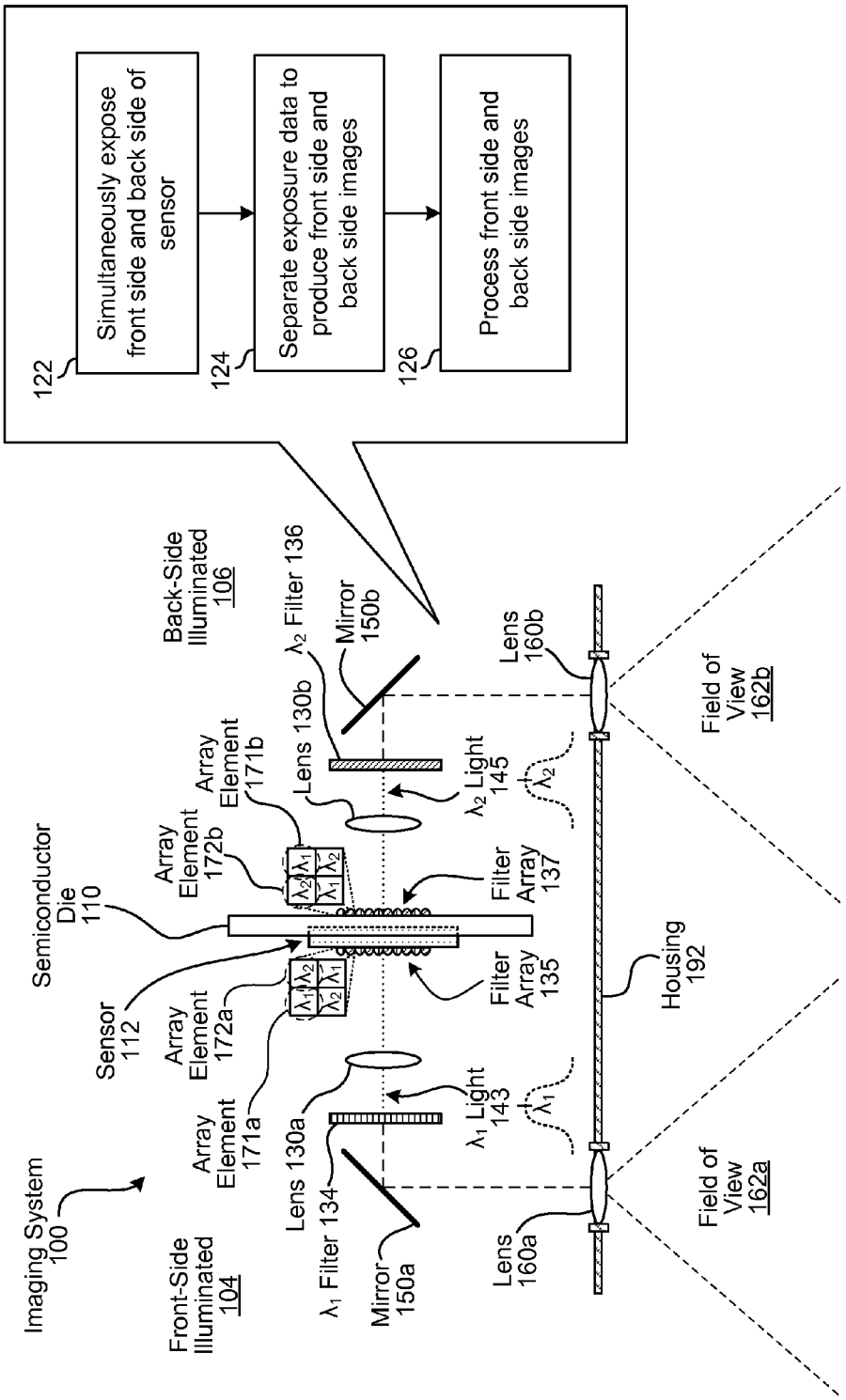

122
Simultaneously expose front side and back side of sensor
124
Separate exposure data to produce front side and back side images
126
Process front side and back side images
Imaging System 100
Front-Side Illuminated 104
Back-Side Illuminated 106
Semiconductor Die 110
Sensor 112
Array Element 172a
Array Element 171a
Array Element 172b
Array Element 171b
Lens 130a
Lens 130b
λ1 Filter 134
λ2 Filter 136
Mirror 150a
Mirror 150b
λ1 Light 143
λ2 Light 145
Filter Array 135
Filter Array 137
Lens 160a
Lens 160b
Housing 192
Field of View 162a
Field of View 162b

FIG. 2A

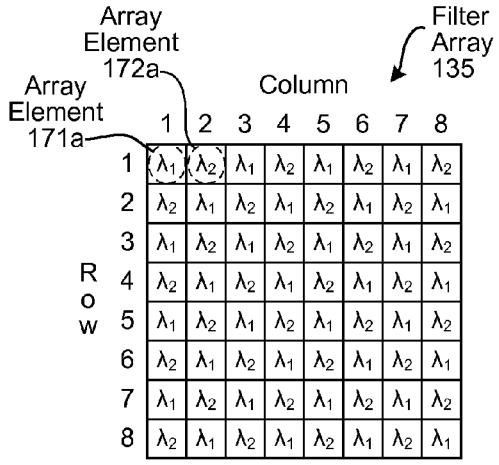


FIG. 2B

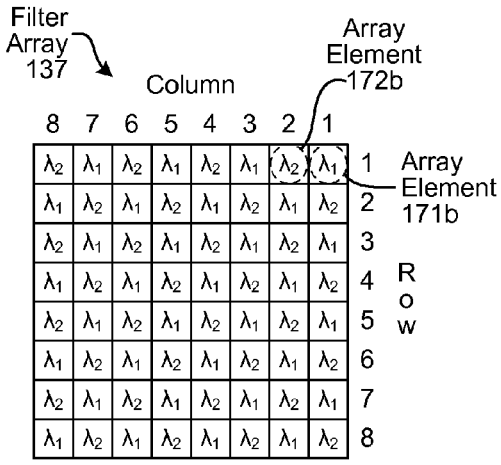


FIG. 3

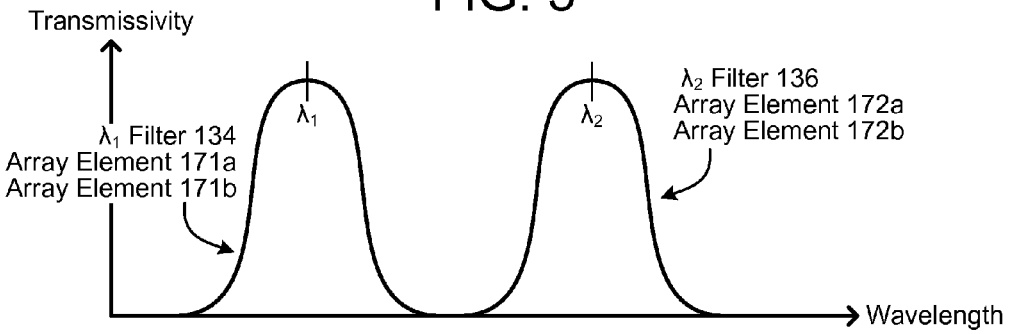


FIG. 4A

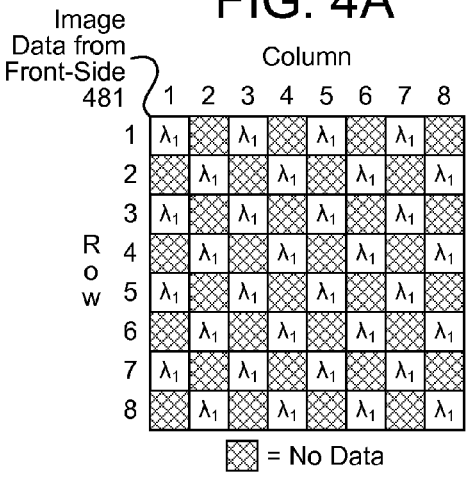


FIG. 4B

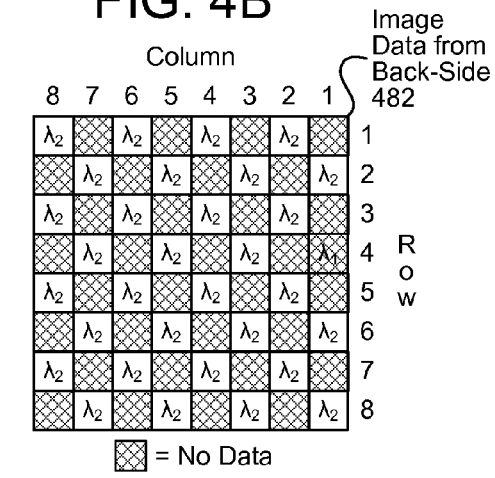


FIG. 5

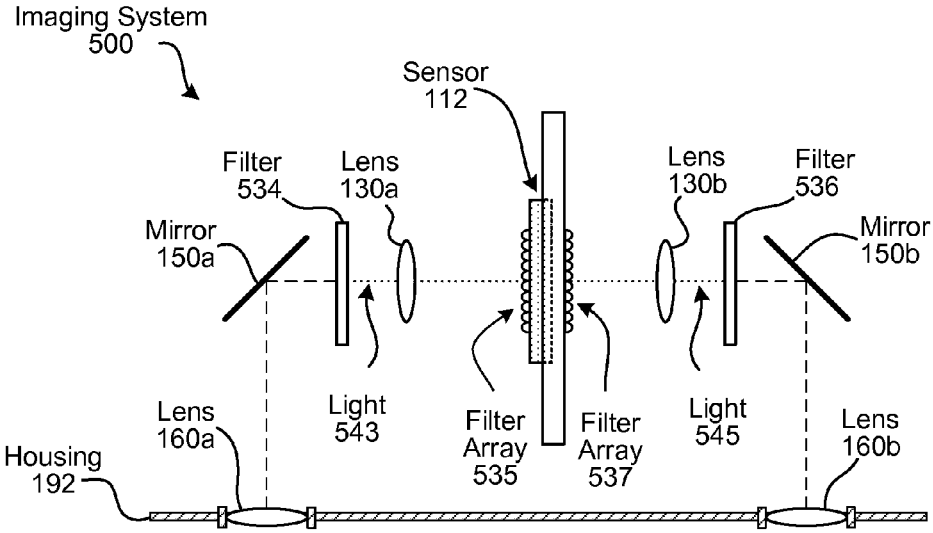


FIG. 6A

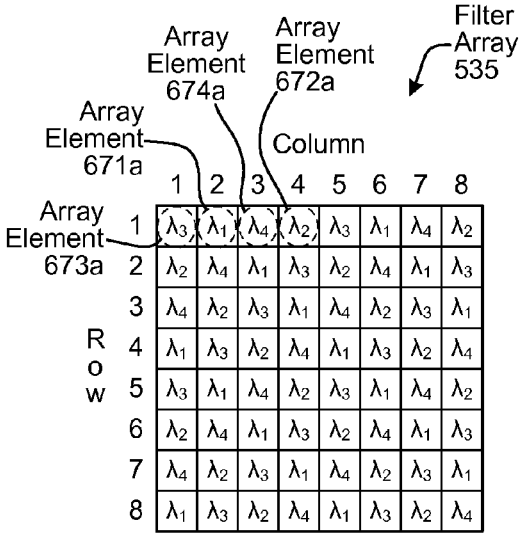


FIG. 6B

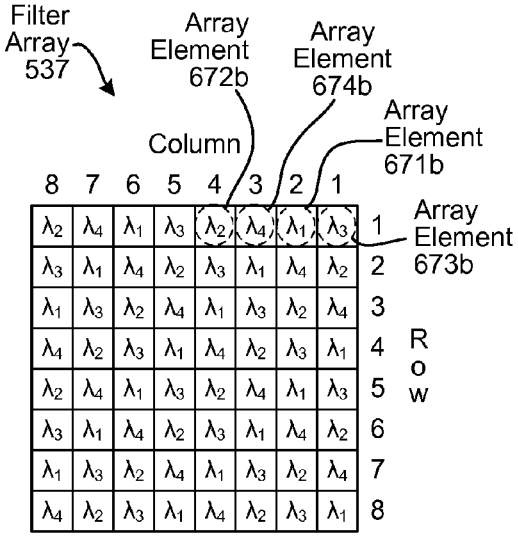


FIG. 7

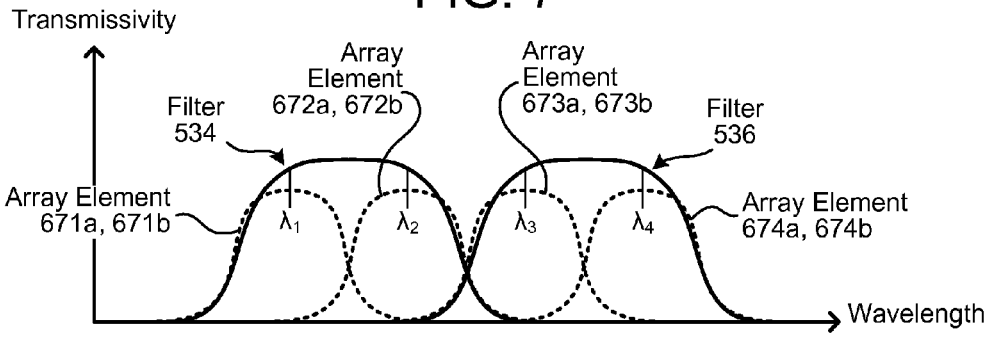


FIG. 8A

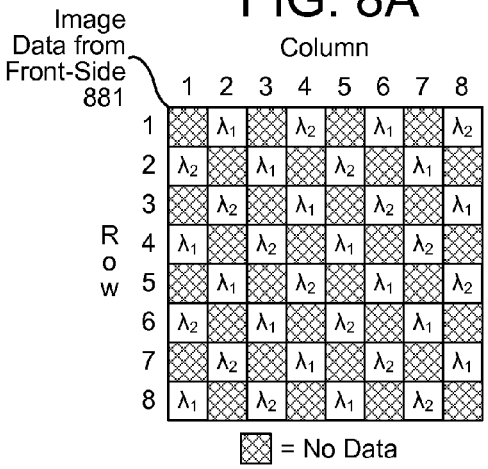


FIG. 8B

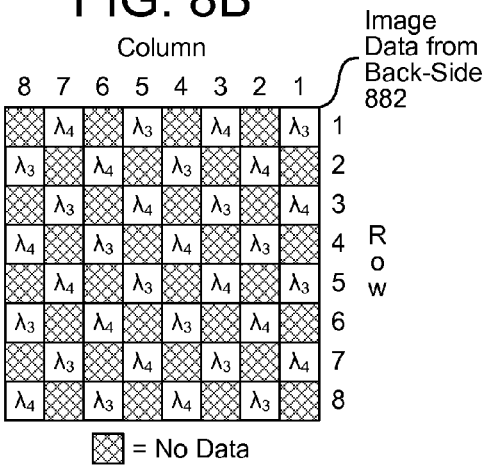


FIG. 9

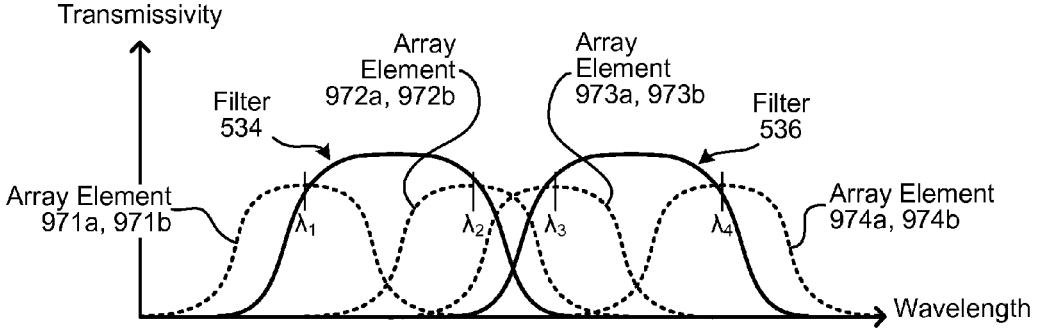


FIG. 10

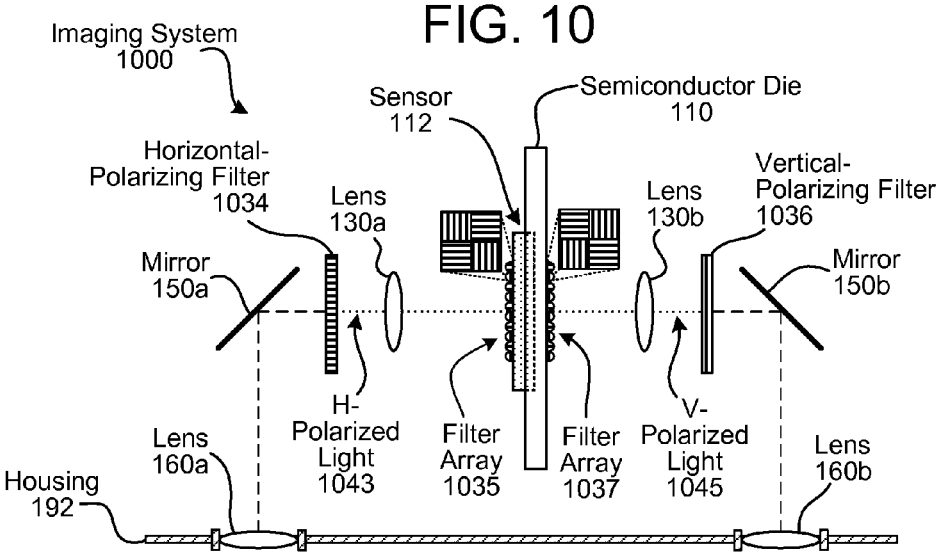


FIG. 11A

Filter Array 1035

Row \ Column	1	2	3	4	5	6	7	8
1	V	H	V	H	V	H	V	H
2	H	V	H	V	H	V	H	V
3	V	H	V	H	V	H	V	H
4	H	V	H	V	H	V	H	V
5	V	H	V	H	V	H	V	H
6	H	V	H	V	H	V	H	V
7	V	H	V	H	V	H	V	H
8	H	V	H	V	H	V	H	V

FIG. 11B

Filter Array 1037

Row \ Column	8	7	6	5	4	3	2	1
1	H	V	H	V	H	V	H	V
2	V	H	V	H	V	H	V	H
3	H	V	H	V	H	V	H	V
4	V	H	V	H	V	H	V	H
5	H	V	H	V	H	V	H	V
6	V	H	V	H	V	H	V	H
7	H	V	H	V	H	V	H	V
8	V	H	V	H	V	H	V	H

FIG. 12A

Image Data from Front-Side 1281

Row \ Column	1	2	3	4	5	6	7	8
1		H		H		H		H
2	H		H		H		H	
3		H		H		H		H
4	H		H		H		H	
5		H		H		H		H
6	H		H		H		H	
7		H		H		H		H
8	H		H		H		H	

= No Data

FIG. 12B

Image Data from Back-Side 1282

Row \ Column	8	7	6	5	4	3	2	1
1		V		V		V		V
2	V		V		V		V	
3		V		V		V		V
4	V		V		V		V	
5		V		V		V		V
6	V		V		V		V	
7		V		V		V		V
8	V		V		V		V	

= No Data

FIG. 13A

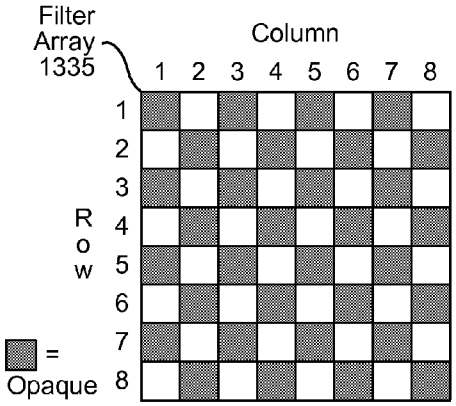


FIG. 13B

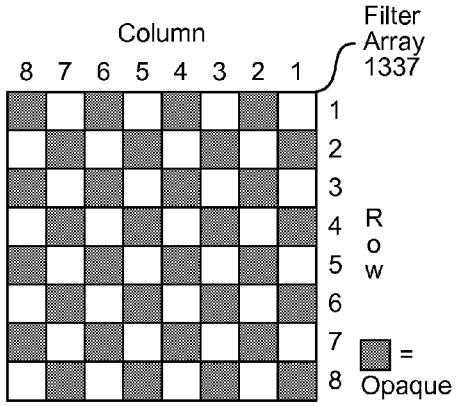


FIG. 14A

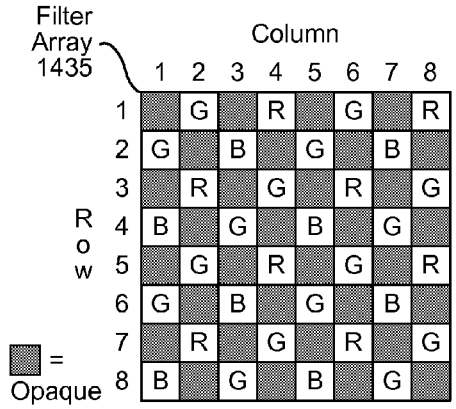


FIG. 14B

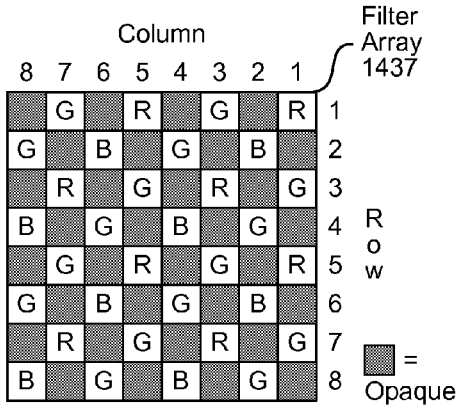


FIG. 15A

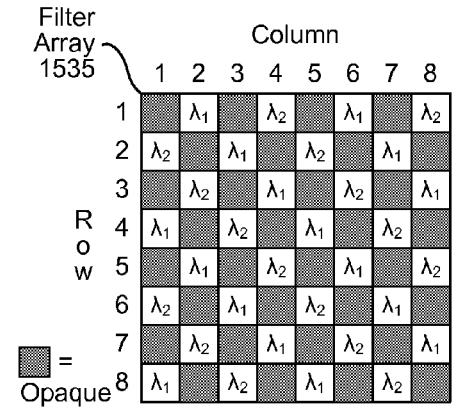


FIG. 15B

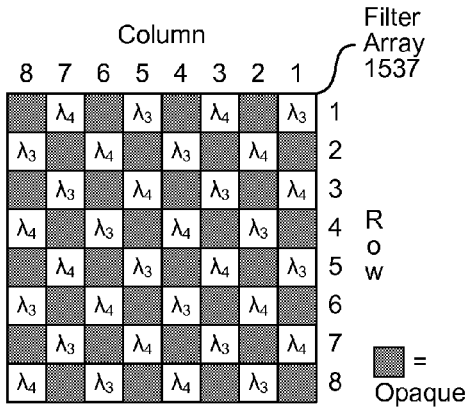


FIG. 16

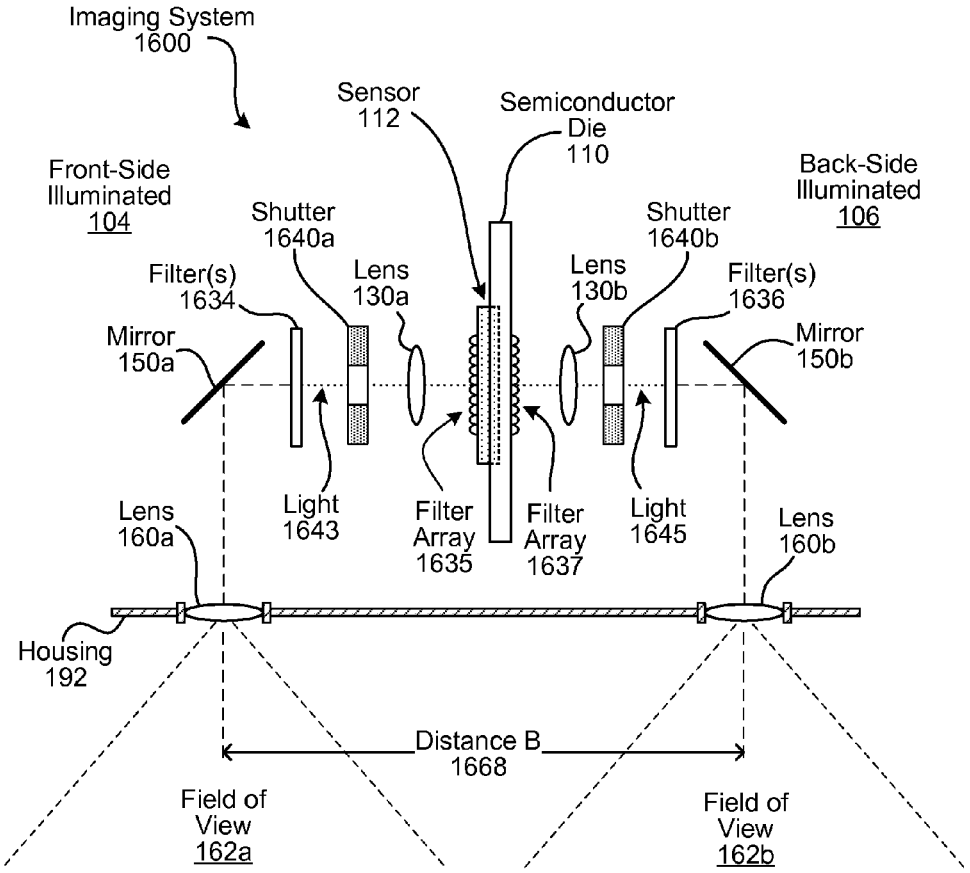

Imaging System
1600
Sensor
112
Semiconductor
Die
110
Front-Side
Illuminated
104
Back-Side
Illuminated
106
Shutter
1640a
Shutter
1640b
Filter(s)
1634
Lens
130a
Lens
130b
Filter(s)
1636
Mirror
150a
Mirror
150b
Lens
160a
Light
1643
Filter
Array
1635
Filter
Array
1637
Light
1645
Lens
160b
Housing
192
Distance B
1668
Field of
View
162a
Field of
View
162b

FIG. 17

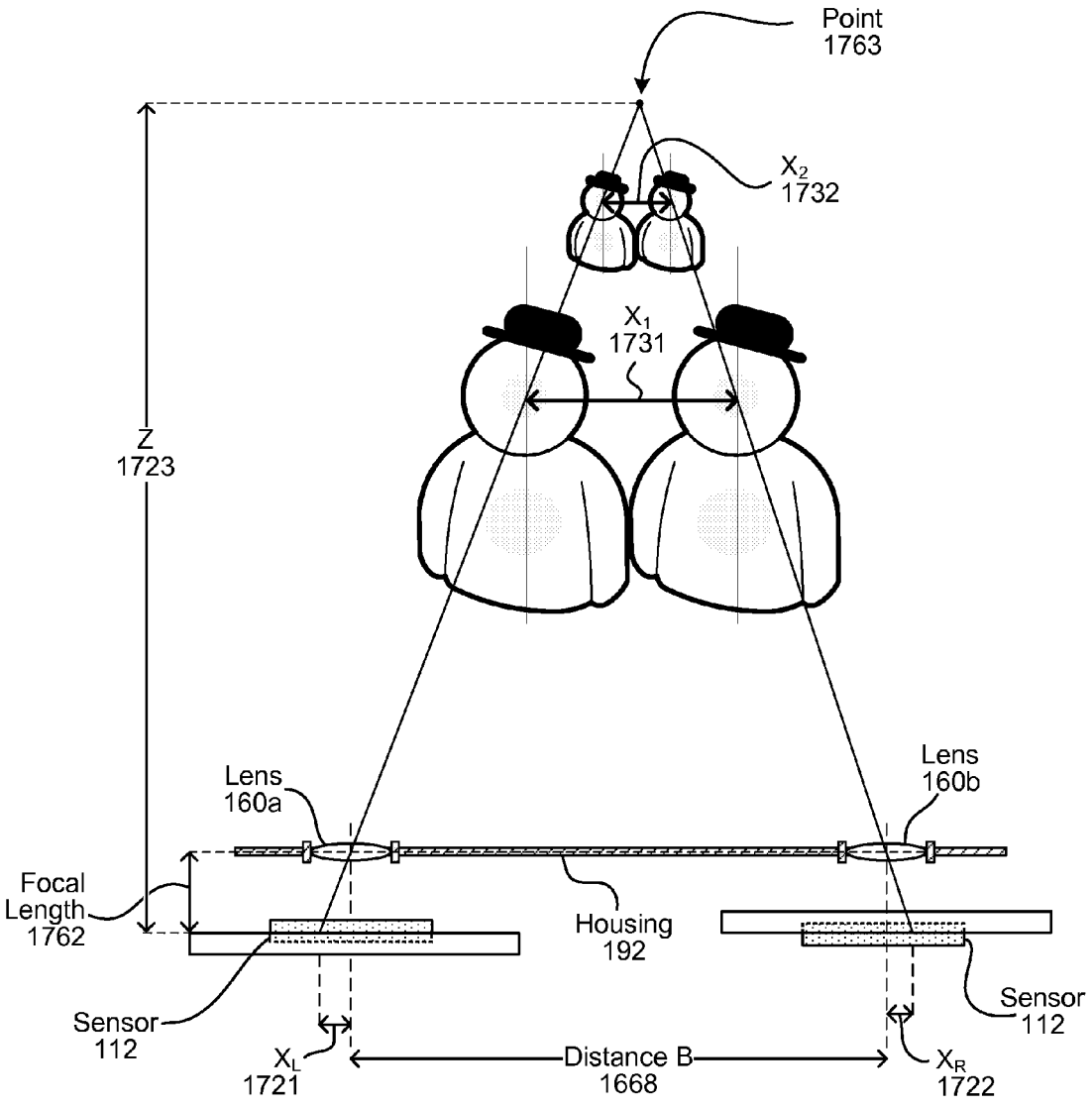

Point
1763
X2
1732
X1
1731
Z
1723
Lens
160a
Lens
160b
Focal
Length
1762
Housing
192
Sensor
112
Sensor
112
XL
1721
Distance B
1668
XR
1722

FIG. 18

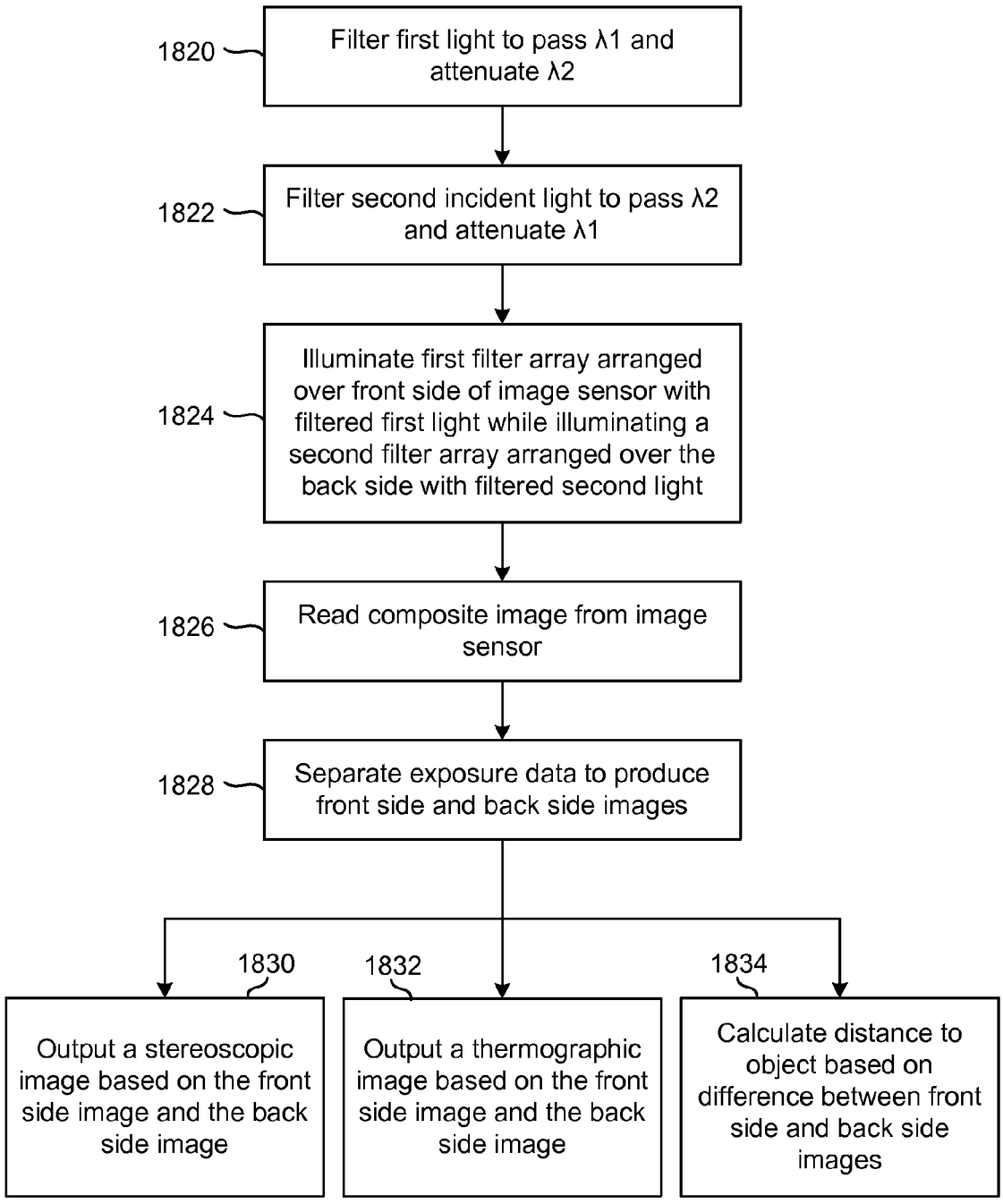
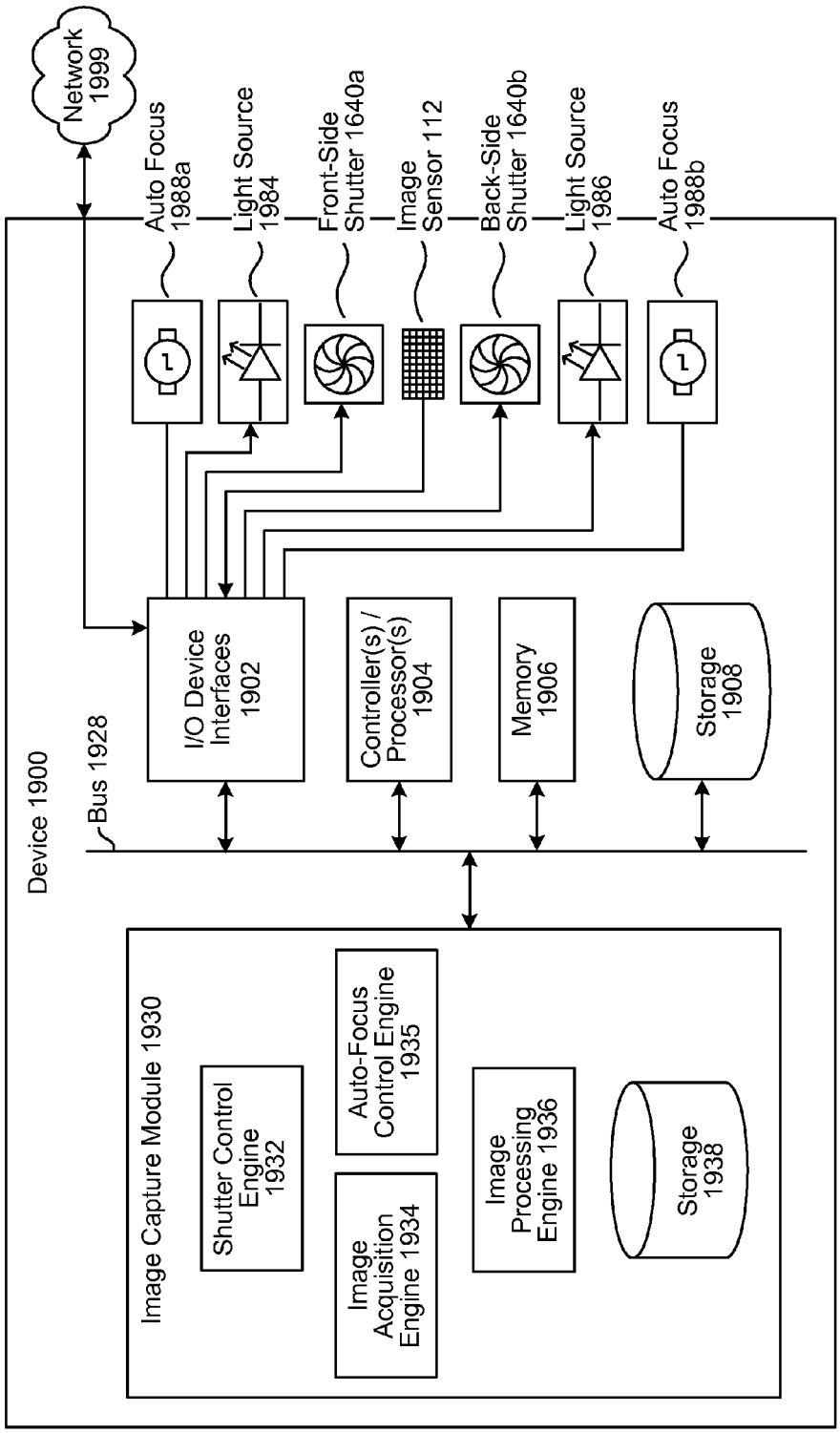

1820
Filter first light to pass λ1 and attenuate λ2
1822
Filter second incident light to pass λ2 and attenuate λ1
1824
Illuminate first filter array arranged over front side of image sensor with filtered first light while illuminating a second filter array arranged over the back side with filtered second light
1826
Read composite image from image sensor
1828
Separate exposure data to produce front side and back side images
1830
1832
1834
Output a stereoscopic image based on the front side image and the back side image
Output a thermographic image based on the front side image and the back side image
Calculate distance to object based on difference between front side and back side images

FIG. 19


Network 1999
Auto Focus 1988a
Light Source 1984
Front-Side Shutter 1640a
Image Sensor 112
Back-Side Shutter 1640b
Light Source 1986
Auto Focus 1988b
Device 1900
Bus 1928
I/O Device Interfaces 1902
Controller(s) / Processor(s) 1904
Memory 1906
Storage 1908
Image Capture Module 1930
Shutter Control Engine 1932
Auto-Focus Control Engine 1935
Image Acquisition Engine 1934
Image Processing Engine 1936
Storage 1938

SINGLE SENSOR TWO-SIDED CAMERA

BACKGROUND

Cameras have become a ubiquitous feature on mobile devices such as cellular telephones. Many such devices include multiple cameras, such as a high resolution camera on the back of the device for digital photography, and a lower resolution camera on the front of the device next to the display to support video telephony and the taking of self-portraits.

BRIEF DESCRIPTION OF DRAWINGS

For a more complete understanding of the present disclosure, reference is now made to the following description taken in conjunction with the accompanying drawings.

FIG. **1** illustrates a system for capturing images using both the front-side and back-side of a single image sensor.

FIGS. **2**A and **2**B illustrate filter arrays that, in conjunction with front-side and back-side filters, enable the system of FIG. **1**.

FIG. **3** illustrates an example of the wavelength-dependent transmissivity the filter array elements and filters used with the system of FIG. **1**.

FIGS. **4**A and **4**B illustrate the image data from the front-side and the back-side of the image sensor in the system of FIG. **1**.

FIG. **5** illustrates a system similar to that in FIG. **1**, but that includes more complex filter arrays.

FIGS. **6**A and **6**B illustrate the filter arrays used with the system in FIG. **5**.

FIG. **7** illustrates an example of the wavelength-dependent transmissivity the filter array elements and filters used with the system of FIG. **5**.

FIGS. **8**A and **8**B illustrate the image data from the front-side and the back-side of the image sensor in the system of FIG. **5**.

FIG. **9** illustrates high-pass and low-pass filtering between the filter array elements and filters using filter array elements with wider pass-bands than those illustrated in FIG. **7**.

FIG. **10** illustrates a system similar to that in FIG. **1**, but that uses polarized filter arrays.

FIGS. **11**A and **11**B illustrate the filter arrays used with the system in FIG. **10**.

FIGS. **12**A and **12**B illustrate the image data from the front-side and the back-side of the image sensor in the system of FIG. **10**.

FIGS. **13**A to **15**B illustrate alternative filter arrays.

FIG. **16** illustrates a system similar to that in FIGS. **1**, **5**, and **10** that includes shutters.

FIG. **17** illustrates geometries that may be used to determine the distance to an object using the left and right images.

FIG. **18** illustrates a process for capturing images using both the front-side and back-side of a single image sensor based on the structures of the systems in FIGS. **1** through **9**.

FIG. **19** is a block diagram conceptually illustrating example components of a device.

Unless stated otherwise, the figures are not drawn to scale and the relative sizes of features are not proportional.

DETAILED DESCRIPTION

Space is at a premium inside mobile devices, where a difference in component sizes on the order of a few millimeters may require significant design trade-offs, impacting device features such as thickness, camera resolution, and battery capacity. Adding multiple cameras to a device entails dedicating space for additional optical systems (lenses, shutters, etc.), as well as the added space, power, and wiring requirements for an additional image sensor and control electronics.

FIG. **1** illustrates an imaging system **100** where a single image sensor **112** may serve as two cameras. The image sensor **112** is simultaneously (**122**) front-side illuminated (**104**) and back-side illuminated (**106**), producing composite image data. After the composite image data is read from the image sensor **112**, the composite image data is separated (**124**) to produce a discrete front side image and a discrete back side image. The discrete images may then be processed (**126**) in various ways that ordinarily require two separate exposures, such as preparation of stereoscopic images, a composite enhanced image, distance determinations to an object in the images, etc.

To manufacturer an image sensor, multiple image sensors may be constructed on a surface of a semiconductor wafer (also known as a semiconductor substrate). The semiconductor wafer is then divided (e.g., sliced, diced, cut, or cleaved) into multiple smaller "dies." A die including an integrated circuit ("IC") (e.g., sensor **112**) may also be referred to as a "chip." In the parlance of image sensors, light that is shone directly on the image sensor **112** (for example, light through lens **130***a*) is referred to "front-side illumination," and light that passes through the die **110** (for example, light through lens **130***b*) to reach the image sensor is referred to as "back-side illumination." Thus, the side of the sensor **112** facing the semiconductor die **110** may be referred to as the back side, while the other side of the sensor **112** may be referred to as the front side.

The front-side illuminated (**104**) side of the imaging system **100** may include an outer lens **160***a* connected to a housing **192** of a device, providing a field of view **162***a*. Light passes through lens **160***a* to a mirror **150***a*, to redirect a path of incident light to reach inner lens **130***a* and the front side of the sensor **112**. Somewhere along the path, the incident light passes through a front-side filter **134**. The filter **134** selectively allows light that is within a range of wavelengths centered around wavelength λ_1 to pass through (i.e., λ_1 light **143**). As illustrated, the filter **134** is between the mirror **150***a* and the inner lens **130***a*.

Similarly, the back-side illuminated (**106**) side of the imaging system **100** may include an outer lens **160***b* connected to a housing **192** of a device, providing a different field of view **162***b* that overlaps with field of view **162***a*. Light passes through lens **160***b* to a mirror **150***b*, to redirect a path of incident light to reach inner lens **130***b* and pass through the semiconductor die **110** to the back side of the sensor **112**. Somewhere along the path, the incident light passes through a back-side filter **136**. The filter **136** selectively allows light that is within a range of wavelengths centered around wavelength λ_2 to pass through (i.e., λ_2 light **145**). As illustrated, the filter **136** is between the mirror **150***b* and the inner lens **130***b*.

A filter array is arranged on each side of the sensor **112**, and the arrangement of the array elements may match the arrangement of pixels in the underlying sensor **112**. As illustrated, the front-side filter array **135** comprises alternating filter elements passing the first wavelength λ_1 (**171***a*) or passing the second wavelength λ_2 (**172***a*). The back-side filter array **137** comprises filter elements with an exact opposite mirror-image pattern, so that a pixel has an array element for λ_1 on both sides (**171***a* on front side, **171***b* on back side), or has an array element for λ_2 on both sides (**172***a* on front side, **172***b* on back side). FIGS. **2**A and **2**B illustrate a larger portion of the filter arrays **135**, **137**, and includes example row and column designations in relation to rows and columns of the pixels of the

underlying sensor **112**. A same row and column equates to an array element arranged to filter light to a photosensor of the sensor **112** having the illustrated row and column location.

By configuring a transmissivity of the front side filter **134** and back side filter **136** as illustrated in FIG. **3**, light having the wavelength λ_1 (**143**) will be received by sensor pixels having λ_1 array elements in the filter array **135**, while wavelength λ_2 will not reach the front-side of the sensor. Likewise, light having the wavelength λ_2 (**145**) will be received by sensor pixels having λ_2 array elements in the filter array **137**, while wavelength λ_1 will not reach the back-side of the sensor. FIGS. **4**A and **4**B illustrate the result image data from the front-side (**481**) and the back-side (**482**), where a grey box indicates that no data was received from the respective side.

For example, if λ_1 corresponds to the color blue and λ_2 corresponds to the color red, only blue light will be recorded from the front-side of the image sensor, and only red light will be recorded from the back-side of the image sensor. Even though the λ_1 filter **134** substantially attenuates (i.e., effectively blocks) light in the λ_2 wavelength band, having λ_2 array elements **172***a* in the filter array **135** mitigates any leakage of light in the λ_2 wavelength band that might reach the front side of the image sensor, either by bypassing the system's front-side optics or resulting from the leakage from the back side of the die **110** to the front side of the sensor **112**. Likewise, Even though the λ_2 filter **136** blocks light in the λ_1 wavelength band, having λ_1 array elements **171***b* in the filter array **137** mitigates any leakage of light in the λ_1 wavelength band that might reach the back side of the image sensor.

A wavelength "band" of light is a range of wavelengths associated with visible and/or non-visible light. For example, FIG. **3** illustrates transmissivity "pass" bands centered on wavelengths λ_1 and λ_2, as the illustrated curves represent the ranges of wavelengths (i.e., the bands) that the respective filters will pass. Visible wavelength bands typically are bands within a range of three-hundred ninety to seven-hundred nanometers (390-700 nm), with "red" being a band of approximately six-hundred twenty to seven-hundred nanometers (620-700 nm), "green" being a band of approximately four-hundred ninety five to five-hundred seventy nanometers (495-570 nm), and "blue" being a band of approximately four-hundred fifty to four-hundred ninety five nanometers (450-495 nm). Infrared (an example of non-visible light) comprises bands of light in the range from seven hundred nanometers to one millimeter (700 nm-1 mm).

The term "band" refers to a generalized range and does not necessarily refer to specific wavelengths, although red, green, and blue filters are often associated with particular ranges. A band may encompass both visible and invisible light, such as a band that includes red and some of the infrared spectrum. The wavelength bands used by the individual filters herein may have ranges in the visible spectrum, the non-visible spectrum, or a combination thereof, and a system may include a mix of filters that pass light in visible and/or non-visible bands.

The filter arrays **135** and **137** may have elements for more than two wavelength bands. For example, a three-color filter array conventionally used with image sensors is a Bayer filter. A Bayer filter is a mosaic color filter array arranged with red, green, and blue color filter elements arranged on a square grid of photodetectors (e.g., photosensors, photo diodes, sensor pixels). A first Bayer filter may be arranged as the filter array **135** on the front side of the sensor **112**. A second Bayer filter with an opposite pattern of elements (i.e., a mirror image arrangement) may be arranged as the filter array **137** on the back side of the sensor **112**. By tuning front side filter **143** to pass blue and green, and tuning back side filter **145** to tune red, the image data from the front side will include blue and green data, whereas the image data from the back side will include red data.

The photodetectors of the image sensor **112** do not independently record a wavelength of incident light, but rather, record a magnitude of incident light. If no color filters are included, for example, the resulting data would correspond to a black-and-white greyscale image. Instead, it is the color filters that are responsible for the data from a photosensor being read as a particular color. So if it is known that a photosensor is aligned with a red filter, the pixel data will be interpreted as red, and if it is known that a photosensor is aligned with a blue filter, the pixel data will be interpreted as blue, and so on. Thus, the "color" of data is based on the location of the photosensor in the image sensor's grid and the associated filters, rather than the data read from the photosensor.

The arrangement of wavelengths of bands passed by the filters **134**, **135**, **136**, and **137** may be different than that shown in FIG. **3**, and the pass bands may have some overlap (e.g., overlapping transmissivity curve "tails" as the transmissivity approaches zero). Such overlap is common in Bayer filters, where for instance, the "tail" of a blue filter transmissivity curve may overlap a tail of a green filter transmissivity curve.

FIG. **5** illustrates a system **500** like that in FIG. **1**, but building on the Bayer filter example, includes filter arrays **535** and **537** with array elements configured for four different wavelength bands, as illustrated in FIGS. **6**A and **6**B. As illustrated in FIG. **7**, the front-side filter **534** is configured to pass both a first wavelength λ_1 and a second wavelength λ_2, whereas the back-side filter **536** is configured to pass both a third wavelength λ_3 and a fourth wavelength λ_4. The result, as illustrated in FIG. **8**, is that image data from the front-side (**881**) comes from photodetectors aligned with λ_1 array elements **671***a* and from photodetectors aligned with λ_2 array elements **672***a*, and image data from the back-side (**882**) comes from photodetectors aligned with λ_3 array elements **673***b* and from photodetectors aligned with λ_4 array elements **674***b*. So instead of having a "color" gamut derived from three filter colors (e.g., red, green, blue), the system **500** has a gamut derived from four filter "colors" (although a color gamut is only an example, as some or all of the wavelength bands may include infrared wavelengths).

However, the two sides of the image sensor can have photodetectors arranges to detect a different number of wavelength bands. For example, if all of the filter elements in FIGS. **6**A and **6**B having the λ_4 pass band are replaced with λ_3 filter elements, the image data from the front side (**881**) would include data from pixels of two different wavelength bands (λ_1, λ_2), whereas the image data from the back side (**882**) would include data from pixels of a single wavelength band (λ_3). In this same manner, the image sensor may collect data corresponding to a different number of wavelength bands on each side (with one or more bands on each side).

The pass bands of the filters **534**, **536** do not necessarily need to align with the pass bands of the filter elements of the filter arrays, as illustrated in FIG. **9**. As illustrated, the front side filter **534** and the back side filter **536** are the same as in system **500**, but the while the wavelength bands of the array elements **671***a* to **674***d* and **671***b* to **674***b* overlap with the filters **534** and **536**, they are transmissive to a broader range of wavelengths. Since the filters **534** and **536** control the range of light that reaches each filter array, cutting off (i.e., substantially attenuating) unwanted wavelengths, the large overlap between filter array elements for λ_2 and for λ_3 does not appreciably alter the results from those described with system **500**

due to the filters **534** and **536** cutting off the overlapping wavelengths on each filter's respective side.

FIG. **10** illustrates a system **1000** like that in FIG. **1**, but which filters based on polarization of light rather than wavelength. Polarization is a property of waves that can oscillate with more than one orientation. Electromagnetic waves, such as light, exhibit polarization. By passing light through a linear polarizing filter, the filter transmits waves having a same polarization orientation as the filter and substantially attenuates waves having a polarity that is perpendicular orientation of the filter. Light with intermediate orientations of polarization may be passed with varying degrees of transmissivity and attenuation. When two filters are arranged in series with perpendicular linear polarization orientations, substantially no light will pass through the combination, whereas when two filters are arranged in series with parallel linear polarization orientations, light will pass through the combination.

In FIG. **10**, the front-side filter is a linear polarizing filter **1034** with a horizontal orientation, and the back-side filter is a linear polarizing filter **1036** with a vertical orientation that is perpendicular to the horizontal orientation. The filter arrays **1035** and **1037** have some array elements with vertical orientation and some array elements with horizontal orientation. As shown in FIGS. **12**A and **12**B, this produces image data from the front-side (**1281**) only from photodetectors aligned with array elements having a horizontal orientation, and from the back-side (**1282**) only from photodetectors aligned with array elements having a vertical orientation.

As noted above, individual photodetectors of the image sensor **112** do not detect "color," such that the arrangement in system **1000** would produce black-and-white images, absent additional filtering. This may be accomplished by also including one or more color filters on each side of the image sensor **112**. For example, specific horizontal polarized pixels elements may be associated with red, green, and blue, and specific vertical polarized pixels elements may be associated with red, green, and blue. Since it is polarization and not color that determines which data originated on which side, the pattern of color pixels on each side may be independent from the other (i.e., something other than the opposite mirror-image arrangement where blue is aligned with blue and red is aligned with red, as discussed with systems **100** and **500**). These color filters may be arranged with the polarizing filters **1034**, **1036**, may be arranged with the filter arrays **1035**, **1037**, or may be arranged somewhere else in the optical path of light that illuminates the respective sides of the sensor **112**.

In the context of polarization, the terms "Vertical" and "Horizontal" are used as a matter of convenience to convey that the linear polarizations are perpendicular to each other, and do not refer to any particular frame of reference.

FIGS. **13**A to **15**B illustrate examples of filter arrays that enable discrete image data to be discerned from each side of the imaging system independent of the front side filter **134** and back side filter **136**.

As illustrated in FIGS. **13**A and **13**B, the filter array **1335** on the front side of the sensor **112** allows light to pass through some elements (illustrated as white elements) and blocks the passage of light through other elements (illustrated as grey elements). The arrangement of array elements in filter array **1337** allows light to reach the photodetectors blocked by filter array **1335**, and blocks light to photodetectors where **1335** allows the passage of light. The filter elements that "block" light are substantially opaque to at least incident wavelengths to which the image sensor **112** is sensitive. The filter elements that "pass" light are substantially transparent at the wavelengths that are passed (and to which the image sensor **112** is sensitive), but may attenuate other wavelengths.

Using filter arrays **1335** and **1337** in FIGS. **13**A and **13**B, each side of the imaging system would produce a black-and-white image, absent additional filtering. FIGS. **14**A and **14**B illustrate a front-side filter array **1435** and a back side filter array **1437** that include red, green, and blue filter elements, such that the composite image data can be separated to create discrete "left" and "right" full color images that were simultaneously captured. The front side array **1535** in FIG. **15**A and back side array **1535** in FIG. **15**B produce the same results from system **500** as illustrated in FIGS. **8**A and **8**B, but without requiring the filters **534** and **536**.

FIG. **16** illustrates a system **1600** based on the other systems already described, but which adds shutters **1640***a* and **1640***b* to each side of the sensor **112** The arrangement of filters **1634** and **1636**, and filter arrays **1635** and **1637** may be any of those already described. Since image data is simultaneously acquired from each side of the systems, a simulated electronic shutter may be used, where exposure time is controlled based on when the image sensor photodetectors are reset, and when their data is read. However, physical shutters **1640***a* and **1640***b* may optionally be included.

Any kind of physical shutter may be used as shutters **1640***a* and **1640***b*, such as mechanical shutters and electronic shutters (e.g., liquid crystal shutters). If a liquid crystal shutter is used, it may result in linearly polarized light. If so, the orientation of the shutter polarization may rotated ninety degrees so that the polarization of light captured by one side of the sensor is perpendicular to the other, eliminating the need for separate polarizing filters **1034** and **1036** (as illustrated with the system **1000**).

Other components may be included in the imaging system **1600** (e.g., systems **100**, **500**, **1000**, etc.), such as additional filters, additional optics, and electromechanical elements (e.g., electromechanical elements to modify zoom or focus). As illustrated, the mirrors **150***a*, **150***b* are angled at forty-five degrees. Other structures may be used to redirect the optical path instead of mirrors **150***a*, **150***b*, such as reflective prisms.

Unfiltered, conventional image sensors can capture both visible light and infrared. Some image sensors can also capture some of the ultraviolet spectrum. Examples of additional filters that the system may include are a high-pass filter to attenuate infrared (passing visible light, which is composed of light having higher frequencies than infrared) and a low-pass filter to attenuate ultraviolet (passing visible light, which is composed of light having lower frequencies than ultraviolet), if ultraviolet and infrared light are unwanted wavelengths.

Although several of the examples have been in terms of image data for visible light, the filters and filter arrays may be configured to pass light of other wavelengths, such as infrared. Infrared filters and visible light filters may also be mixed, with some filter elements passing visible wavelengths and some filter elements passing infrared wavelengths. Infrared filters and filter elements attenuate visible light, but allow light in a portion of the infrared spectrum to pass through.

As arranged in FIG. **16**, depending in part on the overlap of the fields-of-view **162***a* and **162***b* facing in a same direction, the imaging system **1600** can be used for stereoscopic photography. Stereoscopic photography captures two images with a parallax that provides "binocular disparity," simulating human vision by positioning the cameras to have a spatial relationship approximately the same as the left and right eyes on a human head (binocular disparity distance "B" **1668**), and providing similar overlap in the fields of view **162***a*, **162***b* (in comparison to human vision).

The two outer lenses **160***a* and **160***b*, in addition to being spatially offset by the binocular disparity distance "B" **1668**

apart, are in a same plane. The optical path length for light passing through the front-side of the system to the active area of the image sensor **112** and the optical path length for light passing through the back-side of the system to the active area of the image sensor **112** may be equal or close to equal, where an "optical path length" is the product of the geometric length of the path light follows through the system and the index of refraction of the mediums through which it propagates.

Human eyes are horizontally separated by about fifty to seventy eight millimeters (inter-pupillary distance (IPD) between centers of each pupil), with binocular disparity distance **1668** separating lens **160***a* and lens **160***b* corresponding to this IPD range (i.e., fifty to seventy eight millimeters, lens-center to lens-center). The IPD mean value is approximately sixty two millimeters for females, and sixty five millimeters for males, such that the binocular disparity distance **1668** in the range of sixty two to sixty five millimeters may be statistically advantageous. If the optics on both sides of the sensor **112** provide a similar depth of field and focus, then by capturing offset viewpoints of a same scene, a stereoscopic perspective of the scene can be generated, with the overlapping fields of view **162***a*, **162***b* provide a parallax similar to human vision.

By including a filter and/or filter arrays on one side of the system to pass infrared light, or visible light without color registration (i.e., no color filter, resulting in black-and-white grayscale image data), and capturing color data from the other side of the system, and by applying edge detection algorithms to the infrared or unfiltered side, the contrast of edges between front side and back side image may be used to determine the shape of an object or the distance to an object. For example, by looking at two edges of a same object in both front-side derived image data and back-side derived image data, changes between the edges can be used to approximate a change in distance to the object.

For example in FIG. **17**, image data is captured by exposing both sides of the image sensor **112**. Due to parallax produced by lens separation (distance **1668**), a captured object is offset by a distance X_1 (**1731**) due to the difference in the perspectives recorded in the image data from the front side and the image data from the back side. This shift in the object (or edges, or other features, etc.) between sides can be used as a basis for depth measurements.

The disparity between the images is the difference between X_L (**1721**) and X_R (**1722**). The disparity is large when the object is closer, and smaller when the object is further, corresponding to the change in offset X_1 (**1731**) from a first pair of images and offset X_2 (**1732**) from a second pair of images. The offset is not perceptible at and beyond the "vanishing point."

By calculating the distance Z (**1723**) to the point **1763**, the approximate distance to the actual object may be approximated from the image disparity. Using the focal length "f" (**1762**) from the outer lenses **160***a*, **160***b* to the active area of the image sensor, disparity may be determined as:

$$Z = \frac{Bf}{X_L - X_R} \tag{2}$$

where B is binocular disparity distance (**1668**). As B and f are predetermined for the optical system, and X_L and X_R may be determined from the image data, the distance to the object Z may be solved for as:

$$\text{disparity} = X_L - X_R = \frac{Bf}{Z} \tag{1}$$

The example in FIG. **17** uses a same focal length "f" (**1762**) for the front side and back side optical systems. The actual focal length (i.e., the optical path length) may be configured to be approximately the same for both the front side and the back side. Difference in focal length may occur on opposite sides due to differences in refractive indexes of any filters, different geometric path lengths, and the difference in refractive indexes between the surface layers of the sensor **112** from the front side versus the refractive index of the semiconductor die from the backside. In the alternative to engineering the front side and back side optical systems so that the focal lengths are the same on both sides, differences may be adjusted for mathematically, or ignored entirely (an increase in the difference in the optical path lengths resulting in an increase in the probability of error in the distance approximation, if the difference is ignored). The distance approximation Z (**1723**) may be used, for among other things, controlling autofocus mechanisms.

As noted, the wavelengths registered by the filter and filter arrays on each side may be different. For example, one side may acquire color data and the other side may acquire infrared data. While side-dependent data may be extracted from the composite image data (i.e., front side image data and back side image data) and used for distance calculations, in some applications an output image may be based solely on image data from one side or the other, or may be an enhanced image using data from both side. The difference in parallax between perspectives may be corrected computationally during processing, so that the data from both side may be used to form a single image.

For some applications, both sides may configured to capture infrared images. For example, for use in diagnostic equipment for infrared thermography and thermal imaging, one side may include a filters and/or filter arrays tuned to a portion of the infrared spectrum, whereas the other side has a filters and/or filter arrays tuned to a different portion of the infrared spectrum. For infrared thermography applications, a useful range of coverage for the two filter arrays is infrared wavelengths from approximately nine to fourteen microns. So for example, referring to filter arrays **535**, **537**, **1535**, and **1537**, the array elements may pass infrared bands centered at λ_1=9.625 microns, λ_2=10.875 microns, λ_3=12.125 microns, and λ_4=13.375 microns. By combining images captured by opposite sides of the system, a single image sensor may be used to cover the electromagnetic spectrum commonly associated with thermography, providing improved temperature differentiation and wide-band thermography. Other wavelength ranges may also be used, and an individual filter array may have filter array elements spanning fewer or more wavelength bands.

As noted above, the wavelengths transmitted by different filters, filter array elements, and filter-filter array element combinations may be configured to partially overlap (e.g., overlap of Gaussian-curve wavelength sensitivities), with the degree of overlap depending upon, among other things, the choice of filter element materials and the desired dynamic range of the imaging system. By tuning the sides to span different portions of the infrared spectrum, image data recording incident infrared light may be used to approximate a temperature of a radiating object based on the object's black-body radiation characteristics. Black-body radiation has a characteristic, continuous frequency spectrum that

depends only on the body's temperature, called the Planck spectrum or Planck's law. The spectrum is peaked at a characteristic frequency that shifts to higher frequencies with increasing temperature, and at room temperature most of the emission is in the infrared region of the electromagnetic spectrum. By calibrating each side of the imaging system, an approximate temperature of imaged objects may be determined. In the alternative, the infrared filters, filter arrays, and combinations thereof on both sides of the image sensor **112** may be arranged to expose the sensor to the same portions of the infrared spectrum, to generate a stereoscopic thermograph, such as by using polarizing filters to differentiate sides as discussed with system **1000**, or opaque filters as discussed with FIGS. **13**A to **13**B.

If one side of the image sensor is being used to capture infrared and the other side is not, it may be preferable to use the front-side illuminated **104** side of the sensor for the infrared. Although a thinning of the back side of the wafer that may be performed during manufacturing after forming the image sensor **112** may reduce noise resulting from infrared energy on the back side to acceptable levels, there is still an increased likelihood of noise being generated by infrared energy on the back side in comparison to the front side. Even so, either side may be used for either color or infrared.

When using the system for stereoscopic photography, the image sensor may be calibrated to balance out differences in color ratios and brightness from one side to the other (and from one filter element to another). This may be done before or after the image sensor **112** is installed in a device, and application of the calibration coefficients may be performed by programmable logic included on the same die as the image sensor. An alternative solution is to store the calibration coefficients in a nonvolatile memory included on the die, to be accessed by a processor to perform calibration.

An electromechanical zoom mechanism may be integrated with each of the outer lenses **160***a*, **160***b*. Similarly, a focusing mechanism (e.g., moving optics and motor) may be integrated to move both of the inner lenses **130***a*, **130***b* and/or the outer lenses **160***a*, **160***b*, or some other refractive optical component(s) to adjust focus. The optics on the front-side and the back-side may be configured the same, or may be different.

The "ultraviolet spectrum" or "ultraviolet light" refers to the portion of the electromagnetic spectrum with a wavelength shorter than that of visible light, but longer than X-rays, that is, in the range between four hundred nanometers and one hundred nanometers. It is so-named because the spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the color violet.

The "visible spectrum" or "visible light" refers to the portion of the electromagnetic spectrum that is visible to the human eye. A typical human eye will respond to wavelengths from about three-hundred ninety to seven hundred nanometers, which in terms of frequency, corresponds to a band in the vicinity of four hundred thirty to seven hundred ninety terahertz.

"Infrared," the "infrared spectrum," or "infrared light" refers to the portion of the electromagnetic spectrum that extends from about seven hundred nanometers to one millimeter. This range of wavelengths corresponds to a frequency range of approximately four hundred thirty terahertz to three hundred gigahertz. Most of the thermal radiation emitted by objects near room temperature is infrared.

The image sensor **112** may be a complementary metal-oxide semiconductor (CMOS) sensor, and the semiconductor die **110** may be silicon. Existing CMOS sensor designs are readily adaptable to serve as dual-sided sensors. So long as the sensor technology can be modified to allow light to reach pixels from both sides of a sensor, the principles discussed above may be applicable to other sensor technologies besides CMOS.

Also, while a CMOS silicon image sensor can ordinarily sense light across an entirety of the visible spectrum, it may only be able to sense part of the infrared spectrum. Semiconductor materials other than silicon may be used as the substrate and to fabricate the sensors (e.g., III-V semiconductors), depending upon the range of wavelengths to be sensed, so long as the material accommodates the construction of sensors covering the portions of the electromagnetic spectrum to be captured, and does not appreciably attenuate the wavelengths to be captured by back-side illumination.

Although the filter elements of the arrays are illustrated in an alternating interleaved pattern, other configurations are possible, such as alternating vertical stripes of array elements (e.g., alternating stripes of elements **171***a*/b and **172***a*/b), alternating horizontal stripes, etc.

The mirrors **150***a* and **150***b* may be tuned to the wavelengths to be reflected. However, most conventional mirrors reflect both visible light and at least a portion of the infrared spectrum.

A device including any of the above described systems may also include one or more light emission sources to illuminate a scene at wavelengths corresponding to the wavelengths to be captured by the image sensor. For example, the device may include a white source light such as a white light emitting diode (LED) if the image sensor is to capture a color or black-and-white image (e.g., a white LED flash), and an infrared light source such as an infrared LED if the image sensor is to capture an infrared image.

Depending in part on the portions of the electromagnetic spectrum (i.e., different wavelengths of light) being recorded and the sensitivity of the image sensor **112** to those wavelengths, if mechanical shutters **1640***a*, **1640***b* are included in the system, the duration the shutter is open on one side of the image sensor (i.e., exposure time) may be different than the duration the other shutter is open. Conventional shutter-control algorithms may be used to automatically and independently control each shutter.

FIG. **18** illustrates a process based on the systems describe in conjunction with FIGS. **1** to **9**. Incident "first" light is filtered (**1820**) filtering incident first light to include a first wavelength band of light and to substantially attenuate a second wavelength band of light (e.g., λ_1 light **143** in FIG. **1**). Incident "second" light is filtered (**1822**) to include the second wavelength band of light and to substantially attenuate the first wavelength band of light (e.g., λ_2 light **145** in FIG. **1**). Steps **1820** and **1822** are performed at a same time, but if physical shutters **1640***a* and **1640***b* are included in the system one exposure (and the duration of filtering) on one side of the image sensor **112** may be short than the other. Exposure durations may be different, for among other reasons, to avoid saturating the photodetectors receiving first wavelength before the exposure is complete for the second wavelength (and vice versa).

A first filter array (e.g., **135**, **535**) is arranged over the front side of the image sensor and a second filter array (e.g., **137**, **537**) is arranged over the back side of the image sensor. The first filter array is illuminated (**1824**) with the filtered first light at a same time that the second filter array is illuminated with the filtered second light.

Both of the first filter array and the second filter array include first filter elements (e.g., **171***a*, **171***b*, **671***a*, **671***b*, **971***a*, **971***b*) arranged to filter light incident on a first plurality of photodetectors of the image sensor **112**. The first filter

elements are configured to pass the first wavelength band of light (e.g., λ_1) and to substantially attenuate the second wavelength band of light (e.g., λ_2).

Both of the first filter array and the second filter array also include second filter elements arranged to filter light incident on the second plurality of photodetectors. The second filter elements are configured to pass the second wavelength band of light and substantially attenuate the first wavelength band of light.

The composite image data is read (**1826**) from the first and second pluralities of photodetctors, and then separated (**1828**) to produce front side and back side image data corresponding to images from the differing perspectives of the two outer lens **160***a*, **160***b*.

Once separated, a stereoscopic image may be output (**1830**) based on the front side image and the back side image providing left-eye and right-eye perspectives, as discussed in conjunction with FIG. **16**. A thermographic image may be output (**1832**) either by correcting for parallax and combining the corrected front-side and back-side images, or outputting the front side and back side images as a stereoscopic thermographic image (e.g., **1830**). Temperature information may be determined based on black body radiation values to be included in the thermographic image. A distance may be calculated (**1834**) from the difference in perspectives between the front side and back side images, as discussed in conjunction with FIG. **17**. The distance may be used for, among other things, adjusting focus of the device.

The process illustrated in FIG. **18** is readily adapted to the systems described in conjunction with FIGS. **10** to **12**B by replacing the wavelength bands with first and second polarizations that are perpendicular to each other. The process may be adapted to use the partially opaque filter arrays (e.g., **1335**, **1337**, **1435**, **1437**, **1535**, **1537**) discussed in conjunction with FIGS. **13**A to **15**B by (optionally) omitting the filtering steps (**1820**, **1822**). Using the polarizing filters and filter arrays, or opaque filter arrays (with or without additional filters), the light that illuminates the front side and the back side in step **1824** may comprise the same wavelengths or different wavelengths.

FIG. **19** is a block diagram conceptually illustrating example components of a device **1900** including the double-sided image sensor **112**. In operation, the device **1900** may include computer-readable and computer-executable instructions that reside in memory **1906** and/or storage **1908**/**1938**, as will be discussed further below.

Static components of the optical systems such as mirrors and filters are omitted from FIG. **19**. Although components of an auto-focus system are illustrates, other optional dynamic elements such as zoom control are omitted, but operation of such elements is well known in the art. Although illustrated as an auto-focus system, device **1900** may be auto-focus, manual, or fixed focus.

The device **1900** includes input/output (I/O) device interfaces **1902** that support a variety of input and output components. Such components include the image sensor **112**, the front-side shutter **140***a*, the back-side shutter **140***b*, a first light source **1984** for use with the front-side, a second light source **1986** for use with the back-side, a front-side illumination auto focus mechanism **1988***a*, and a back-side illumination auto-focus mechanism **1988***b*. Although the shutters **140***a*, **140***b* in FIG. **19** are illustrated as mechanical shutters, electronic shutters such as liquid crystal shutters may be used instead. As noted above, a simulated electronic shutter may also be used, such that shutters **140***a*, **140***b* may be omitted.

The first light source **1984** emits light of a wavelength or range of wavelengths that will pass through the front-side filter(s) and/or filter elements to illuminate a front side of the image sensor, and may be used as a flash or similar illumination. Likewise, the second light source **1986** emits light of a wavelength or range of wavelengths that will pass through the back-side filter(s) and/or filter elements to illuminate a back side of the image sensor, and may be used as a flash or similar illumination. As discussed above, the wavelengths emitted by the first and second light source **1984**, **1986** may be different, such as one emitting white light and the other infrared, or both emitting infrared (e.g., same spectra or emitting in different parts of the infrared spectrum), depending on the configuration.

The I/O device interfaces **1902** may also provide wired or wireless connectivity to connect to external components and/or a network **1999**, such as providing wired connectivity via a universal serial bus (USB) and/or Ethernet port, and/or wireless connectivity for a wireless local area network (WLAN) (such as WiFi) radio, Bluetooth, a Long Term Evolution (LTE) network, WiMAX network, 3G network, etc. In addition to the wired ports and wireless connectivity, one or more ports may be provided for a memory card (not illustrated), such as CompactFlash and Secure Digital (SD) cards.

The I/O device interfaces **1902** may support a wide variety of other input and output components, in addition to those illustrated.

The device **1900** may include an address/data bus **1928** for conveying data among components of the device **1900**. Each component within the device **1900** may also be directly connected to other components in addition to (or instead of) being connected to other components across the bus **1928**.

The device **1900** may include one or more controllers/processors **1904**, that may each include a central processing unit (CPU) for processing data and computer-readable instructions, and a memory **1906** for storing data and instructions. The memory **1906** may include volatile random access memory (RAM), non-volatile read only memory (ROM), non-volatile RAM and/or other types of memory. The device **1900** may also include a data storage component **1908**, for storing data and controller/processor-executable instructions (e.g., instructions to perform steps **122** to **126** in FIG. **1** and steps **1820** to **1834** in FIG. **18**, and to perform the distance calculations discussed with FIG. **17**). The data storage components **1908** and **1938** are of a non-volatile storage type such as optical, magnetic, or solid-state storage (e.g., Flash, magnetoresistive, phase-change). In addition, a portion of data storage component may be external to or added to the device **1900**, such as storage connected via the USB or Ethernet port, or as a memory card.

Computer instructions for operating the device **1900** and its various components may be executed by the controller(s)/processor(s) **1904**, using the memory **1906** as temporary "working" storage at runtime. The computer instructions may be stored in a non-transitory manner in non-volatile memory **1906** or storage **1908**/**1938**. Alternatively, some or all of the executable instructions may be embedded in hardware or firmware in addition to or instead of software.

The device **1900** further includes an image capture module **1930** that manages image acquisition and processing.

A shutter control engine **1932** of the image capture module **1930** controls the timing of the resetting and reading of the image sensor **112** is a simulated shutter is used, and controls operation of shutters **140***a* and **140***b* if physical shutters are used. The shutter control engine **1932** works in coordination with the image acquisition engine **1934** to control exposure duration, and may verify that image data to be recorded from

the image sensor **112** has been fully offloaded from the sensor and that the image sensor **112** has been reset before permitting another exposure.

The image acquisition engine **1934** controls conventional operations, such as exposure duration and picture type (e.g., one image, stereoscopic, video capture, etc.). The image acquisition engine **1934** may work in coordination with auto-focus control engine **1935**, which controls the front side and back side auto-focus mechanisms **1988***a*, **1988***b*. If a distance calculation is performed as discussed with FIG. **17** (e.g., determining distance to an object in a center of the frames to adjust focus for a subsequent exposure) and step **1834** in FIG. **18**, that calculation may be performed by the auto-focus control engine **1935**.

When image data is to be recorded, the image acquisition engine offloads the image data from the image sensor **112** into memory **1906** and/or storage **1908**/**1938**, and may reset the image sensor. The image acquisition engine may be specialized, may be of a conventional design used with dual-camera devices modified to acquire stereoscopic images, or some combination thereof. The image acquisition engine **1934** may determine whether the first light source **1984** or second light source **1986** is needed, and based on that determination, the activation of the respective light source may be controlled by either the shutter control engine **1932** (to insure that the timing of the illumination synchronizes with shutter operation) or by image acquisition engine **1934** itself.

The image processing engine **1936** may separate image data acquired from the front side and image data acquired from the back side to generate discrete front-and-back image data. The image processing engine **1936** also formats recorded image data, such as converting a captured image data into, among other things, a "JPEG" (Joint Photographic Experts Group), bitmap, "TIFF" (Tagged Image File Format), and/or raw image, into an "MPEG" (Moving Pictures Expert Group) or HEVC (High Efficiency Video Coding) video format, and/or wrapping/bundling data into videos or other multiple-image formats.

If calibration of the front and back sides of the image sensor **112** is performed by the device **1900**, the image acquisition engine **1934** may compare front-side and back-side images and calculate calibration coefficients. The calibration coefficients may then be stored in storage **1938**, and used by image process engine **1936** when processing images. If calibration is done prior to the integration of the sensor **112** into the device **1900**, the calibration coefficients may also be stored in storage **1938**.

As noted above, programmable logic and nonvolatile memory may be fabricated on the dies, together with the image sensors. Some or all of the engines of image capture module **1930**, as well as the I/O device interfaces **1902**, controller(s)/processor(s) **1904**, memory **1906** may be integrated on the semiconductor die **110** with the image sensor **112**. Any type of programmable logic may be included (e.g., an application specific integrated circuit (ASIC), a microprocessor, a field programmable gate array (FPGA), etc.). Shutter control engine **1932** may be implemented, among other ways, as a state machine. Some or all of storage **1908**/**1938** may also be integrated on the semiconductor die **110** as solid-state memory (e.g., Flash, magnetoresistive random access memory (MRAM)) and/or read-only memory. The calibration coefficients and software/firmware-based executable instructions used by the programmable logic (if any) may be stored on-die.

The above aspects of the present disclosure are meant to be illustrative. They were chosen to explain the principles and application of the disclosure and are not intended to be exhaustive or to limit the disclosure. Many modifications and variations of the disclosed aspects may be apparent to those of skill in the art. Persons having ordinary skill in the field of electro optics, optical sensors, optics, digital cameras, and infrared and stereoscopic photography should recognize that components and process steps described herein may be interchangeable with other components or steps, or combinations of components or steps, and still achieve the benefits and advantages of the present disclosure. For example, in each of the illustrated imaging systems (**100**, **500**, **1000**, **1600**), optical components may be arranged in a different, such as the position of the filters relative to the mirror. As another example, the optical components on one side of the sensor **112** may be different than the optical components on the other. Moreover, it should be apparent to one skilled in the art, that the disclosure may be practiced without some or all of the specific details and steps disclosed herein.

As used in this disclosure, the term "a" or "one" may include one or more items unless specifically stated otherwise. Further, the phrase "based on" is intended to mean "based at least in part on" unless specifically stated otherwise.

What is claimed is:

1. A device, comprising:

an image sensor having a front side and a back side, the back side being opposite the front side, with the image sensor configured to be illuminated from the front side and configured to be illuminated from the back side;

a first lens exposed to an exterior of the device to transmit incident light from the exterior of the device to the front side of the image sensor;

a second lens exposed to the exterior of the device to transmit incident light from the exterior of the device to the back side of the image sensor, the second lens arranged in a same plane as the first lens;

a first filter array comprising a first plurality of filter elements disposed between the first lens and the front side of the image sensor, and arranged to transmit light to the image sensor, the first plurality of filter elements comprising first filter elements and second filter elements;

a second filter array comprising a second plurality of filter elements disposed between the second lens and the back side of the image sensor, and arranged to transmit light to the image sensor, the second plurality of filter elements comprising the first filter elements and the second filter elements; and

a controller configured to:

read composite image data from the image sensor resulting from exposing the image sensor to light on the front side and the back side at a same time;

extract first image data from the composite image data, comprising image data resulting from the exposing the front side of the image sensor; and

extract second image data from the composite image data, comprising image data resulting from the exposing the back side of the image sensor,

wherein the first image data and the second image data correspond to different perspectives of a same scene.

2. The device of claim **1**, wherein the first plurality of filter elements are arranged as a mirror-image of the second plurality of filter elements, the device further comprising:

a first filter that allows a first wavelength band of light to pass through to illuminate the first filter array and that substantially attenuates a second wavelength band of light; and

a second filter that allows the second wavelength band of light to pass through to illuminate the second filter array and that substantially attenuates the first wavelength band of light,

wherein the first filter elements of the first and second filter arrays are configured to pass the first wavelength band and to substantially attenuate the second wavelength band, and the second filter elements are configured to pass the second wavelength band and to substantially attenuate the first wavelength band,

the first image data is based on light received by the image sensor in the first wavelength band, and

the second image data is based on light received by the image sensor in the second wavelength band.

3. The device of claim **1**, wherein:

the first filter elements transmit incident light and the second filter elements are opaque to incident light,

the first filter elements of the first filter array transmit incident light to illuminate a first set of photodetectors of the image sensor, and the second filter elements of the first filter array block incident light to a second set of photodetectors of the image sensor,

the first filter elements of the second filter array transmit incident light to illuminate the second set of photodetectors of the image sensor, and the second filter elements of the second filter array block incident light to the first set of photodetectors of the image sensor,

the first image data is based on light received by the first set of photodetectors, and

the second image data is based on light received by the second set of photodetectors.

4. A system comprising:

an image sensor, the image sensor comprising a front side and a back side, the back side being opposite the front side, with the image sensor configured to be illuminated from the front side and configured to be illuminated from the back side;

a first lens arranged to direct light to illuminate the front side of the image sensor;

a second lens arranged to direct light to illuminate the back side of the image sensor;

a first filter array disposed between the first lens and the front side of the image sensor and comprising first filter elements arranged to transmit light to the image sensor;

a second filter array disposed between the second lens and the back side of the image sensor and comprising second filter elements arranged to transmit light to the image sensor; and

a controller configured to:

read composite image data from the image sensor, the composite image data resulting from exposing the front side and the back side of the image sensor to the light at substantially a same time;

extract first image data from the composite image data, the first image data comprising image data resulting from the exposing the front side of the image sensor; and

extract second image data from the composite image data, the second image data comprising image data resulting from the exposing the back side of the image sensor.

5. The system of claim **4**, wherein:

the first filter array is arranged as a mirror-image of the second filter array,

the first filter elements of the first filter array are configured to pass a first wavelength band of light and to substantially attenuate a second wavelength band of light,

the second filter elements of the second filter array are configured to pass the second wavelength band and to substantially attenuate the first wavelength band,

the first image data is based on light received by the image sensor in the first wavelength band, and

the second image data is based on light received by the image sensor in the second wavelength band.

6. The system of claim **5**, further comprising:

a first filter that allows the first wavelength band to pass through to illuminate the first filter array, and that substantially attenuates the second wavelength band; and

a second filter that allows the second wavelength band to pass through to illuminate the second filter array, and that substantially attenuates the first wavelength band.

7. The system of claim **4**, further comprising:

a first polarizing filter that allows light having a first polarity to pass through to illuminate the front side of the image sensor, and that blocks light having a second polarity that is perpendicular to the first polarity; and

a second polarizing filter that allows light having the second polarity to pass through to illuminate the back side of the image sensor, and that blocks light having the first polarity,

wherein the first filter array is arranged as a mirror-image of the second filter array,

the first filter elements are configured to pass light having the first polarity and to block light having the second polarity,

the second filter elements are configured to pass light having the second polarity and to block light having the first polarity,

the first image data is based on light received by the image sensor with the first polarity, and

the second image data is based on light received by the image sensor with the second polarity.

8. The system of claim **4**, the first filter array further comprising third filter elements and the second filter array further comprising fourth filter elements, wherein:

the first filter elements of the first filter array transmit incident light to illuminate a first set of photodetectors of the image sensor,

the second filter elements of the second filter array transmit incident light to illuminate a second set of photodetectors of the image sensor,

the third filter elements of the first filter array block incident light from reaching the second set of photodetectors of the image sensor,

the fourth filter elements of the second filter array block incident light from reaching the first set of photodetectors of the image sensor,

the first image data is based on light received by the first set of photodetectors, and

the second image data is based on light received by the second set of photodetectors.

9. The system of claim **8**, wherein, at least one of the first filter elements and at least one of the second filter elements passes incident light in a first wavelength band and substantially attenuates incident light in a second wavelength band.

10. The system of claim **4**, wherein:

the first lens and the second lens are arranged in a same plane and a spatial separation between the first lens and the second lens is between fifty and seventy eight millimeters as measured from centers of each lens, and

the controller is further configured to output a stereoscopic image based on the first image data and the second image data.

11. The system of claim 4, further comprising:
a first shutter arranged to selectively pass light to illuminate the front side of the image sensor;
a first mirror disposed between the first lens and the front side of the image sensor to redirect light to illuminate the front side of the image sensor;
a second shutter arranged to selectively pass light to illuminate the back side of the image sensor; and
a second mirror disposed between the second lens and the back side of the image sensor to redirect light to illuminate the back side of the image sensor.

12. The system of claim 4, the controller further configured to calculate a distance to an object based on a difference in perspective between the first image data and the second image data.

13. The system of claim 4, wherein:
the first filter elements are configured to substantially attenuate visible light and to allow infrared light of a first portion of an infrared spectrum to pass through;
the second filter elements are configured to substantially attenuate visible light and to allow infrared light of a second portion of an infrared spectrum to pass through;
the first image data is based on light received by the image sensor in the first portion of the infrared spectrum;
the second image data is based on light received by the image sensor in the second portion of the infrared spectrum; and
the controller is further configured to combine the first image data and the second image data to provide a thermographic image.

14. A method of operating a device, comprising:
illuminating a first plurality of photodetectors of an image sensor from a front side of the image sensor and a second plurality of photodetectors of the image sensor from a back side of the image sensor at a same time;
reading the first and second pluralities of photodetctors as composite image data; and
separating the composite image data into first image data and second image data, wherein the composite image data corresponding to the exposing of the front side of the image sensor is included in the first image data, and the composite image data corresponding to the exposing of the back side of the image sensor is included in the second image data.

15. The method of claim 14, wherein illuminating the first and second pluralities of photodetectors comprises:
filtering incident first light to include a first wavelength band of light and to substantially attenuate a second wavelength band of light;
filtering incident second light to include the second wavelength band of light and to substantially attenuate the first wavelength band of light;
illuminating a first filter array arranged over the front side of the image sensor with the filtered first light;
illuminating a second filter array arranged over the back side of the image sensor with the filtered second light;
wherein both of the first filter array and the second filter array comprise:
first filter elements arranged to filter light incident on the first plurality of photodetectors, the first filter elements configured to pass the first wavelength band of light and to substantially attenuate the second wavelength band of light, and
second filter elements arranged to filter light incident on the second plurality of photodetectors, the second filter elements configured to pass the second wavelength band of light and substantially attenuate the first wavelength band of light.

16. The method of claim 14, wherein illuminating the first and second pluralities of photodetectors comprises:
filtering incident first light to include light having a first polarity and to substantially attenuate light having a second polarity perpendicular to the first polarity;
filtering incident second light to include light having the second polarity and to substantially attenuate light having the first polarity;
illuminating a first filter array arranged over the front side of the image sensor with the filtered first light;
illuminating a second filter array arranged over the back side of the image sensor with the filtered second light;
wherein both of the first filter array and the second filter array comprise:
first filter elements arranged to filter light incident on the first plurality of photodetectors, the first filter elements configured to pass the first polarity of light and to substantially attenuate the second polarity of light, and
second filter elements arranged to filter light incident on the second plurality of photodetectors, the second filter elements configured to pass the second polarity of light and to substantially attenuate the first polarity of light.

17. The method of claim 14, wherein illuminating the first and second pluralities of photodetectors comprises:
illuminating a first filter array arranged over the front side of the image sensor with the filtered first light; and
illuminating a second filter array arranged over the back side of the image sensor with the filtered second light,
wherein first filter elements of the first filter array arranged over the first plurality of photodetectors pass incident light and second filter elements of the first filter array arranged over the second plurality of photodetectors block incident light, and
third filter elements of the second filter array arranged over the second plurality of photodetectors pass incident light and fourth filter elements of the second filter array arranged over the first plurality of photodetectors block incident light.

18. The method of claim 14, further comprising:
outputting a stereoscopic image based on the first image data and the second image data.

19. The method of claim 14, further comprising:
calculating a distance to an object based on a difference in perspective between the first image data and the second image data.

20. The method of claim 19, further comprising:
adjusting an optical focus of the device based on the calculated distance.

21. The method of claim 14, further comprising:
outputting at least one thermographic image based on the first image data and the second image data.

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